UNDERSTANDING and USING

MAGNETOSTRICTIVE DELAY LINES

The advent of present day miniaturized computer circuitry, establishes the requirement for "miniaturized memory" devices. Modern magnetostrictive delay line memory devices meet this requirement, offering considerable advantages in size, weight, maintenance and cost. Maglines with their associated solid state circuitry provide small, inexpensive and extremely reliable memory units. Bit rates to 4 MC N.R.Z. are now standard with G.I. Maglines providing storage capacities well in excess of 15,000 bits in a single line. With series connected lines bit storage capacities of over 1.5 megabits are attainable. Along with basic magnetostrictive delay line technology G.I. has made important strides in advancing the state of the art with encapsulation and micro-miniature techniques. G.I. encapsulated Maglines (Pat. Pending) fill the military requirements for operation in high shock and vibration environments.

Some of the applications that Maglines have been used in are as follows:

* Digital Storage Devices
* Carrier Operated PCM and FM Digital Communication System
* Radar Ranging Devices
* Radar Simulators
* Sonar Correlators
* Geophysical Devices
* Simultaneous event integrators
* Analog Computers

The basic theory and systems involved in the design of Magnetostrictive Delay Lines, as well as typical parameters, applications, test methods and specification procedures are outlined in the following paragraphs.

A) TRANSMISSION CHARACTERISTICS

An ideal line would have a bandpass characteristic as shown in Fig. I. It must be noted that this drawing has a normalized amplitude characteristic. The insertion loss is not shown. Another characteristic which should be noted, particularly in analog operation, is the flatness of the response. The delay line response will vary approximately $\frac{1}{2}$db from the center amplitude response in a frequency approximately 1/3 either side of the center frequency. With a center frequency f_o, a magnetostrictive delay line has a bandwidth of f_o, 3db points occurring at $-\frac{1}{2}f_o$ and $+\frac{1}{2}f_o$. This holds true for most delay lines operating in a range of 100-700 kc center frequency. For lines above this frequency and up to the 5 mc range, the fall-off point can be between 3 and 6 db. A figure of merit which is used in evaluating a delay line is the delay bandwidth product, for which the phase and amplitude characteristics approach the ideal. By proper design practical delay lines approach these ideal characteristics for delay bandwidth products up to 20,000 at the present time, with a target of 30,000 quite possible in the near future.

The value of center frequency f_o is basically a function of transducer design and in particular its effective magnet length. This is different from the geometrical length because of flux linkages at the end of the coil.

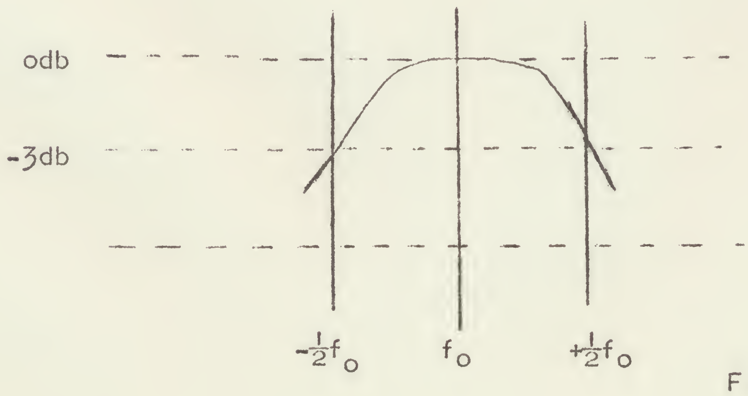


Fig. I

B) TEMPERATURE CHARACTERISTICS

The most common method of specifying temperature variations in delay lines as a function of delay shift and temperatrue is to use the coefficient of delay as specified in PPM/°C. This relation is defined as:

$$T_c = \frac{\Delta T_d \times 10^6}{T_d \times \Delta t^\circ C}$$

Where the maximum allowable shift is known.

$$\Delta T_d = T_c \times \Delta t^\circ C \times T_d \times 10^{-6}$$

Where the temperature coefficient in PPM/°C is known

T_c = Temperature coefficient in PPM/°C

T_d = Time Delay in microseconds

t = Temperature

It is therefore necessary that the delay variations be specified as the total allowable shift from the nominal delay over the temperature range.

C) TEMPERATURE COEFFICIENT OF DELAY

The amplitude coefficient is generally most important in trigger applications since a change in amplitude can cause an effective change in delay. If the requirements are known, lines can be designed in which the amplitude and delay coefficients are compensatory and the effective change in delay over the range of 0°C to +75°C can be held to less than 1 ppm/C°.

In digital applications the changes in amplitude are not sufficiently great to be troublesome. Careful choice of materials used for delay lines prevents variation of signal to noise ratio with temperature.

D) IMPEDANCES

Input and output impedances can be designed to suit circuit requirements. By utilizing transistor circuitry, it has been found that the input transducer impedance should be about 150 ohms with capacitance less than 50 pf. Output transducers are designed for use with a 3.3 k ohm load, capacitance less than 30 pf. These transducers are, therefore, regarded as standard and supplied unless otherwise specified.

E) SIGNAL TO NOISE RATIO

Static noise is measured by observing the voltage amplitude ratio of the output due to a single input pulse, and voltage amplitude due to the acoustical and electrical noise generated by the input within the line. It is a useful measure of effectiveness of the line terminations and complete soundness of the welds.

Dynamic noise is measured by circulating a complex pattern through the line with a constant input amplitude and then observing noise appearing at the output in relation to the smallest amplitude output pulse. The dynamic signal to noise ratio is usually less than the static signal to noise. This is due to the effect that the in phase and out of phase reflections both add and subtract from the signal.

When the electronic logic circuitry is supplied with the delay lines, signal to noise ratios are of no concern to the user. The triggering thresholds are factory set so that the flip flop outputs are clean and duplicate the input logic.

F) DELAY ADJUSTMENT

A noteworthy feature of G.I. magnetostrictive delay lines is their incorporation of a delay adjustment. This adjustment of total delay is of the vernier type and normally has a range of $\pm$ 2 u/sec from the specified delay.

G) TAPS

The tap energy from the delay line, therefore, the number of taps is limited only by the mechanical distance which these taps may be spaced from each other. It must be noted that the LDL type delay line, a longitudinal device, uses this type of specific tapping, although here a coaxial magnetic field is set up with a permanent magnet. Again in this particular type of line the taps are limited only by physical dimensions.

H) ENVIRONMENTAL & SPECIAL PACKAGING

G.I. delay lines can be supplied to suit either military or commercial environmental requirements. Having no moving parts the delay line is inherently rugged. Standard packages to suit many environmental conditions are available as fully engineered products on short delivery. Lines to any one of the wide range of delays, and any specified center frequency within the specifications stated by G.I., can be supplied using these packages. Where required environmental or package specifications cannot be met with existing packages, the standard sizes may often be used for initial engineering models and enable work to proceed during the development of a special package. Some of these units are continuously variable delay lines with a great many taps. The use of special encapsulation techniques insure stability in high orders of shock and vibration.

I) RECORDING TECHNIQUES

Output Waveshape

The output voltage pulse from a delay line is, to a first approximation, the second derivative of the input current waveform. Thus a step of current in the input coil will produce an output waveform as shown in Fig. 2, where the time duration between positive and negative peaks of the dipulse is $T_o/2$. The voltage at the receive transducer for a pulse is shown in Fig. 3. This may be understood by combining two dipoles of step current where the positive peak is twice the amplitude of either of the negative peaks.

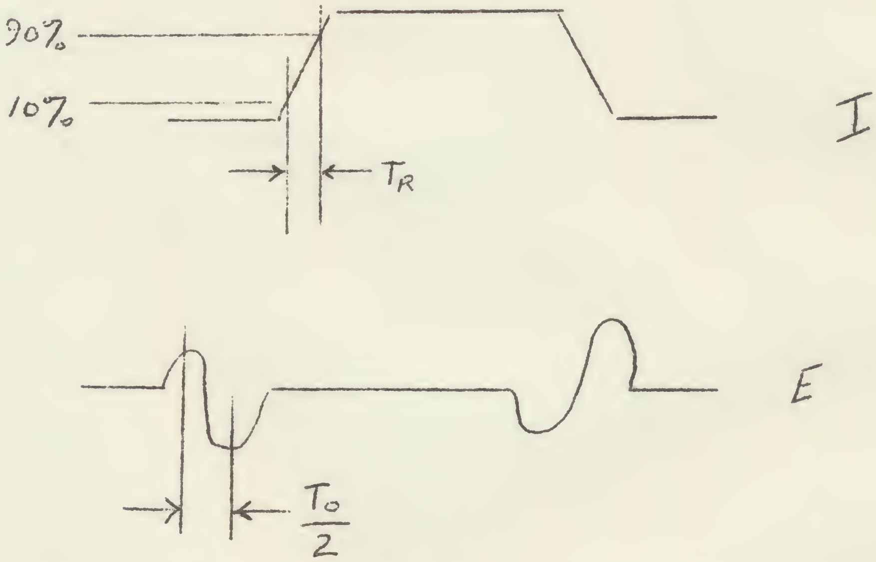
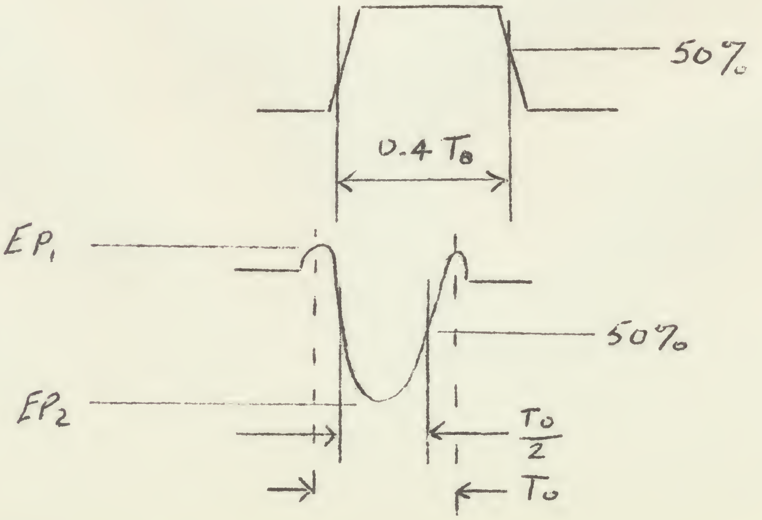


FIG 2



RZ MODE

FIG 3

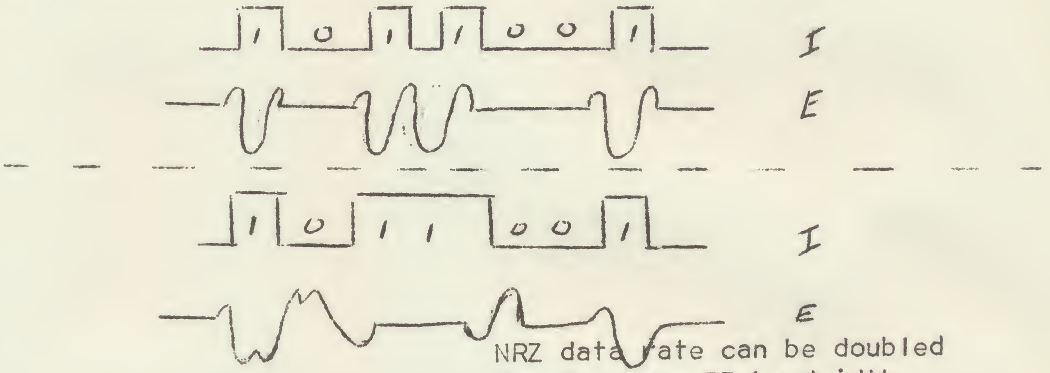
J) <u>RETURN TO ZERO RECORDING (RZ)</u>

The most common method of recording digital information is to represent a "one" by a pulse and a "zero" by the absence of a pulse. This is called a return to zero or RZ method, because the current returns to zero between successive bits of information. The maximum bit rate at which the delay line should be used in order to provide adequate operating margins is equal to the bandwidth of the line or the center frequency f_o. This corresponds to a minimum spacing between bits of "1". The width of the input pulse should not exceed 0.5 f_o and generally 0.4 f_o or less will yield a greater operating tolerance. A typical input pattern for RZ recording is shown in Fig. 3 together with the output waveform from the delay line. No time delay is shown for the sake of clarity. The rise time of t_r of the current pulse should be in the range of $0.1t_o$ to $0.15\ t_o$ where $t_o = 1/f_o$.

If the delay line is being used for storage purposes, it is necessary to amplify the line output and reset it for both time and amplitude before recirculation. Amplification is conventional, the only requirements being to provide sufficient signal and bandwidth to drive a retiming gate. Several methods are available for retiming, the choice depending mainly on the ease with which the delay line characteristics of the line can be attained. If the delay line can be readily made to have a delay drift of less than ± 0.1 u/sec over the required temperature range, the simplest and most economical method of retiming is to "and" the output of the linear amplifier with a strobo clock having a pulse duration in the order of $0.1t_o$.

K) NON-RETURN TO ZERO (NRZ)

NRZ logic system defines a "one" at a voltage level different than that of a "zero" voltage level. The difference with respect to RZ is that each "one" is not a discrete pulse but is represented by a level change. A string of "ones" will be represented by a suitable pulse with duration equal to the aggregate duration of the "ones". The string of "zeros" will be represented by the absence of data in the delay line. (See Fig. 4)

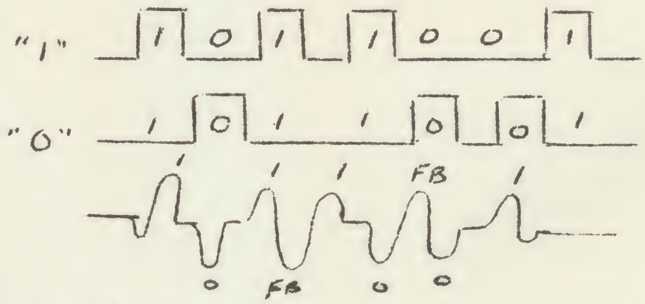


NRZ data rate can be doubled for the same RZ bandwidth.

Fig. 4

L) BI-POLAR

In this mode a "one" and a "zero" are written opposite polarities. Current is thus normally always flowing in the transducer in one direction or the other. (See Fig. 5) The bi-polar method has great advantages in systems where shock and vibration are dominant factors of the environmental conditions.



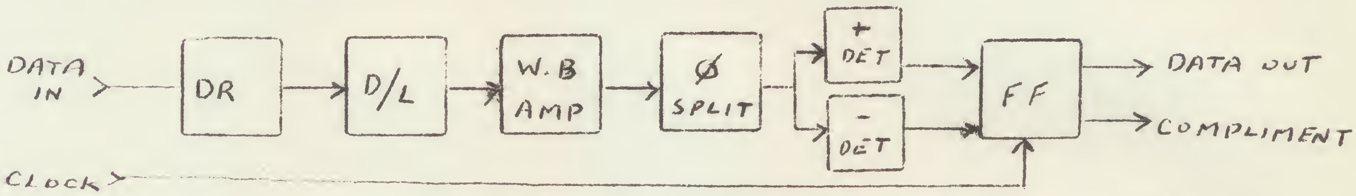
Bi-Polar data mode

Fig. 5

The two false bits (FB) will not appear in the output logic due to non coincidence with the clock strobe.

M) Delay line circuitry is available in both standard and microcircuit packages. The electronics packages are specifically designed to accept a multitude of input-output parameters and D.C. voltage levels depending on the customers requirements. Standard assemblies are available to interface with Fairchild Micrologic, TI-53 series and G.I. computer elements. Input-output voltage ratios of 1:1 are standard with all G.I. Maglines when supplied with circuitry.

N) A functional description of our N.R.Z. electronics package is as follows:



An N.R.Z. input signal is applied to the delay line driver amplifier. A logical "1" is represented by a more positive voltage level. The delay line driver converts the input logic to a current drive to launch the current pulse along the acoustic media. The delay line input transducer differentiates the input waveform as does the output transducer which results in a voltage doublet.

The sense amplifier or broad band video amplifier increases the output of the delay line to drive the phase splitter. The phase splitter splits the delay line output and routes the proper polarity pulses to the detectors.

The psoitive and negative detectors accept either positive or negative polarity voltages respectively and reject the opposite polarities. The detector outputs set and reset the flip flop to recover the stored information.

Flip Flop outputs are fed to emitter followers, which provide low impedance outputs to the system. The outputs from the emitter followers are clamped to the power supply voltages and ground, assuring load insensitive outputs. Both R-S and J-K flops are used depending on whether the logic system requires clock gating or not.

Several input gates are also available for clocked coincidence input requirements.

The output waveforms shown in Figures 2, 3, 4 and 5 are with only driver and sense amplifiers supplied. The outputs from a full logic package will duplicate the input data.

O) The RZ and Bi-polar function diagrams are as follows:

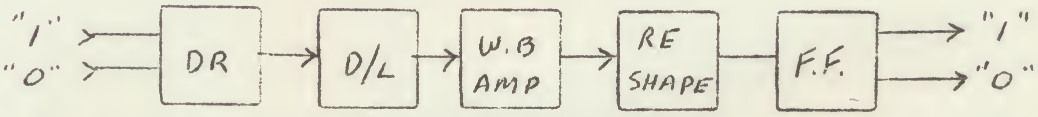


FIG. 6

The block functions are similar to those described for N.R.Z. operation.

P) Measuring the simultaniety of several events with a one trace scope can be accomplished as follows:

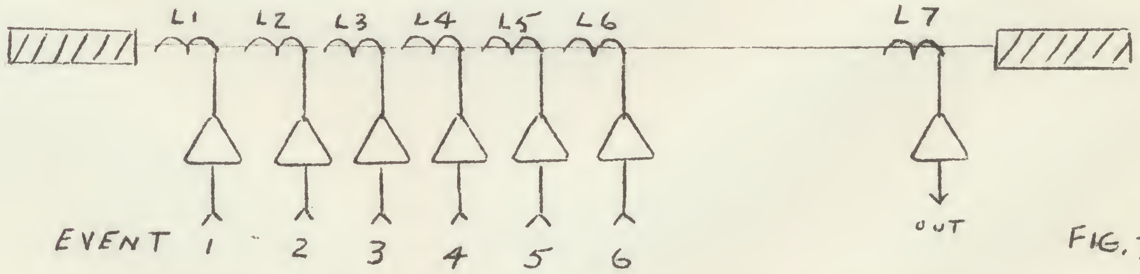


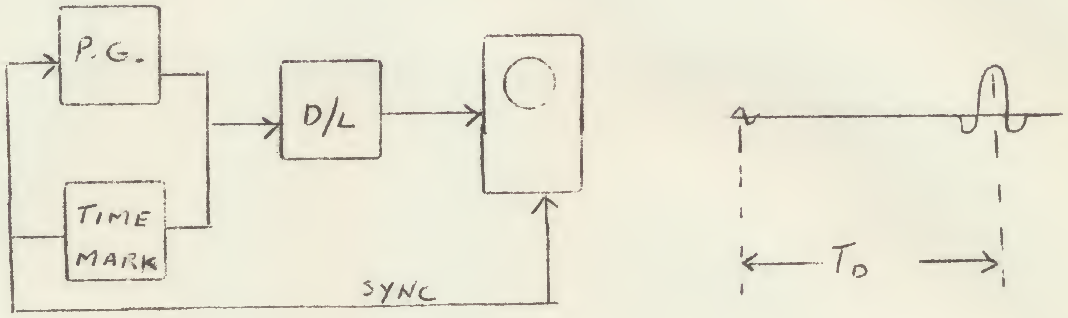
FIG. 7

Each of the events are fed to amplifiers 1 through 6 and output of L7 and its read amplifier are fed to a suitable oscilloscope. With a known spacing in time between L1, L2 etc., the scope display will measure the simultaniety or lack of, and the discrete differences if they exist.

The number of input transducers is only limited by the physical spacing and total delay length. This delay line negates the use of many multi trace scopes and displays all of the data on a single trace.

Q) TEST METHODS

STATIC



DYNAMIC

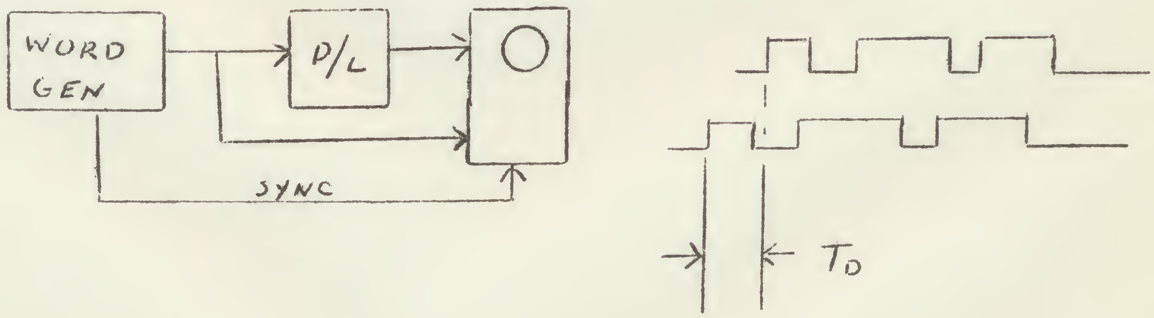


FIG 9

R) SPECIFYING DIGITAL DELAY LINES

Specifications should include the following:

1. Total delay, or total storage capacity, and tolerances
2. Maximum bit rate
3. Mode of operation (RZ or NRZ)
4. Video pulse or bit characteristics: width, amplitude, rise and fall times, etc.
5. Signal-to-noise ratio
6. Input and output admittances
7. Load resistance
8. Pulse attenuation
9. Operating temperature range, and stability within that range
10. Physical size, packaging, and type of connectors
11. Environmental requirements

A general description of the application, with schematics of driving and amplifying circuitry, is also useful.

Milton Grudin
Manager Marketing
Magnetostrictive Delay Lines

GENERAL INSTRUMENT CORPORATION
Radio Receptor Division
Hicksville, New York